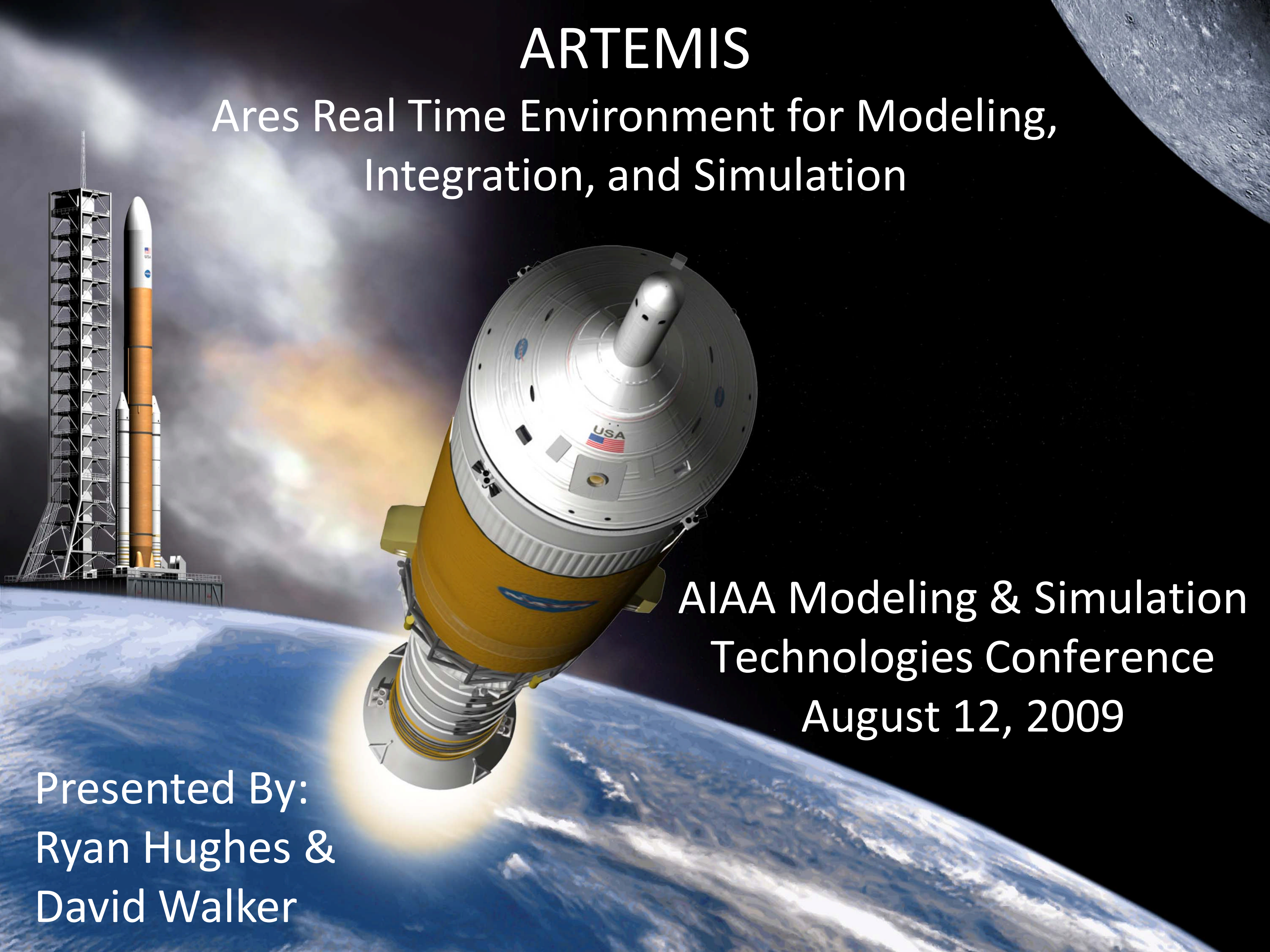


ARTEMIS

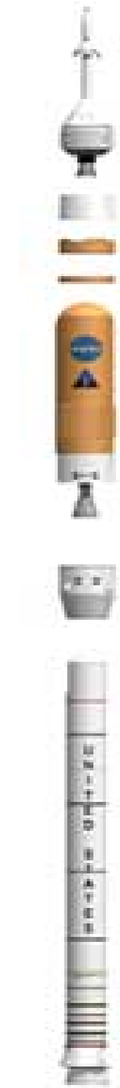
Ares Real Time Environment for Modeling, Integration, and Simulation

AIAA Modeling & Simulation Technologies Conference
August 12, 2009

Presented By:
Ryan Hughes &
David Walker

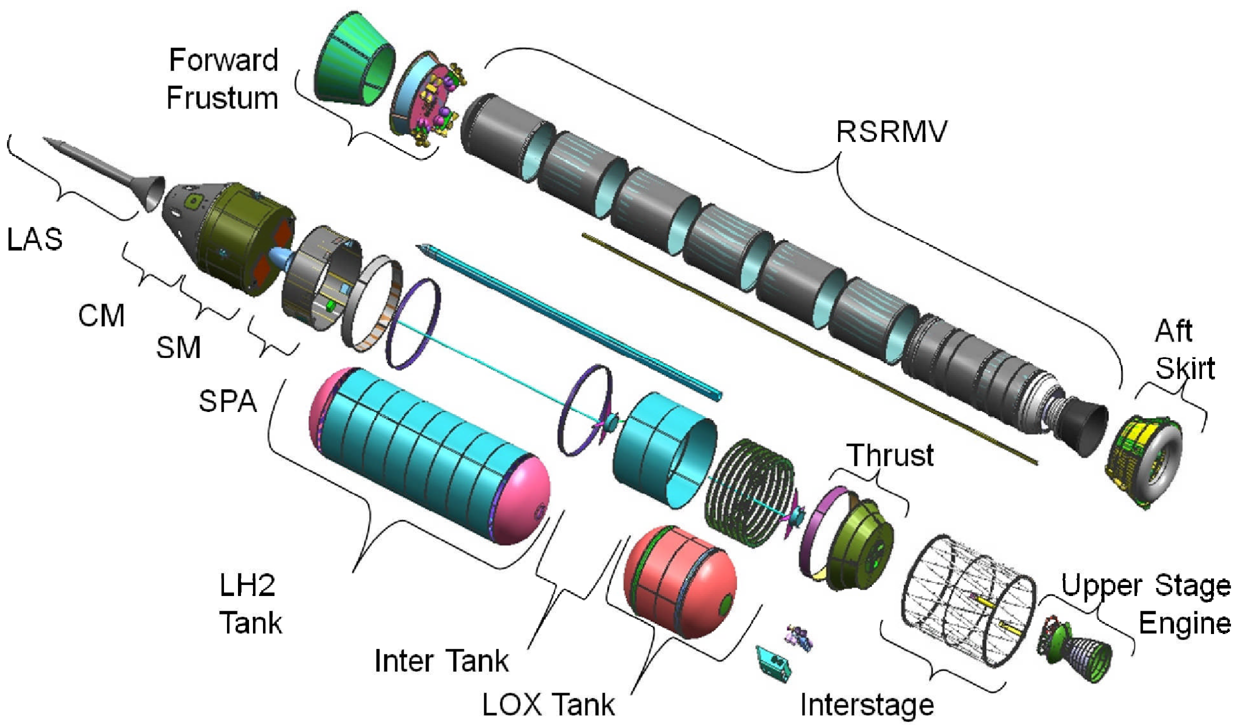
Ares Overview

- Ares I - Launch Vehicle for Orion Crew Module
- Two Stage Rocket
  - First Stage – Reusable Solid Rocket Motor
  - Upper Stage – Liquid Engine (LH2, LOX)
- Ares V will carry Lunar Surface Access Module (LSAM) and Earth Departure Stage to join with Orion for lunar missions



ARTEMIS Overview

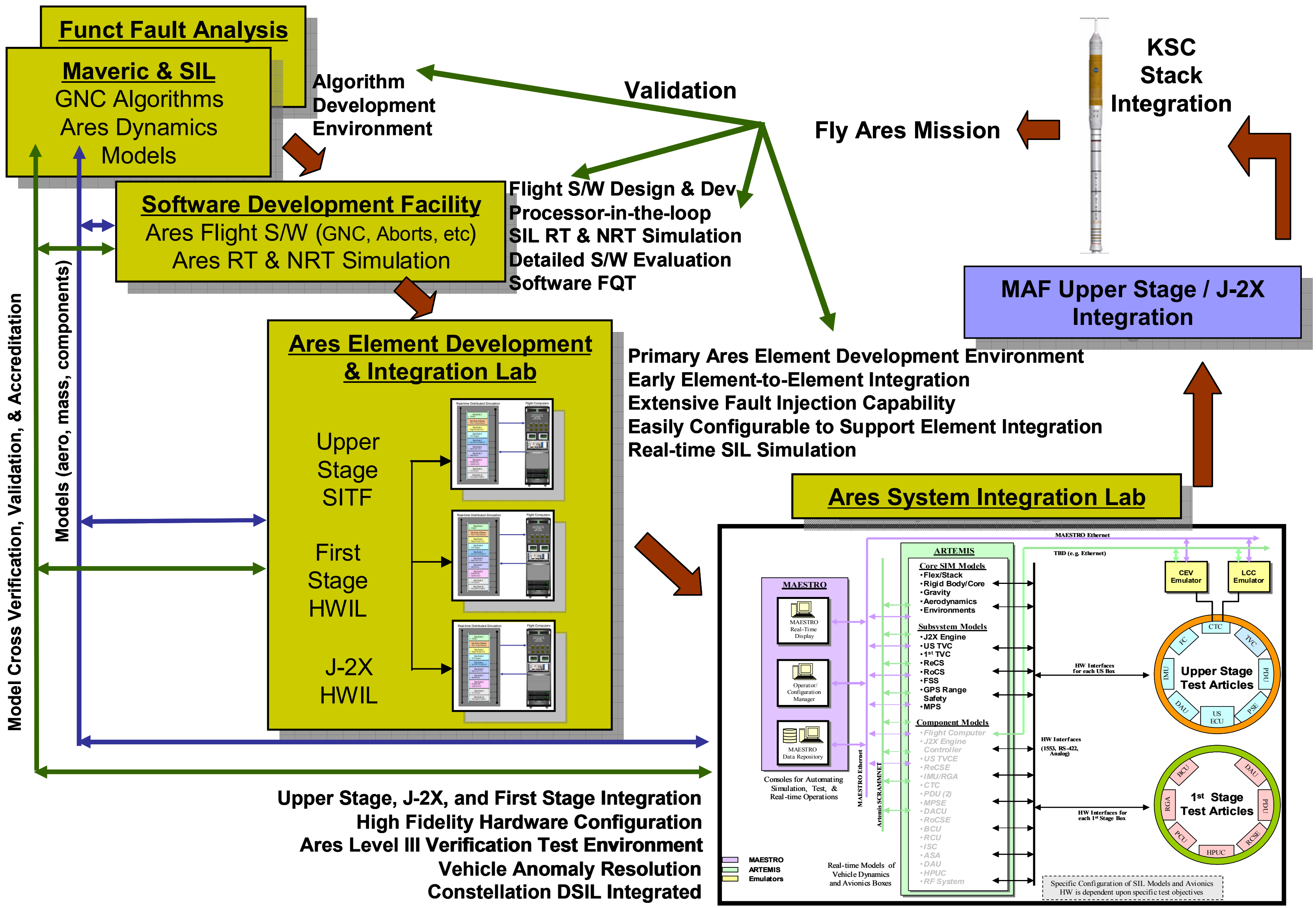
- Ares Real Time Environment for Modeling, Simulation and Integration (ARTEMIS) is the real time simulation supporting Ares I hardware-in-the-loop (HWIL) testing
- ARTEMIS accurately models all Ares / Orion / Ground subsystems which interact with Ares avionics components from pre-launch through orbit insertion



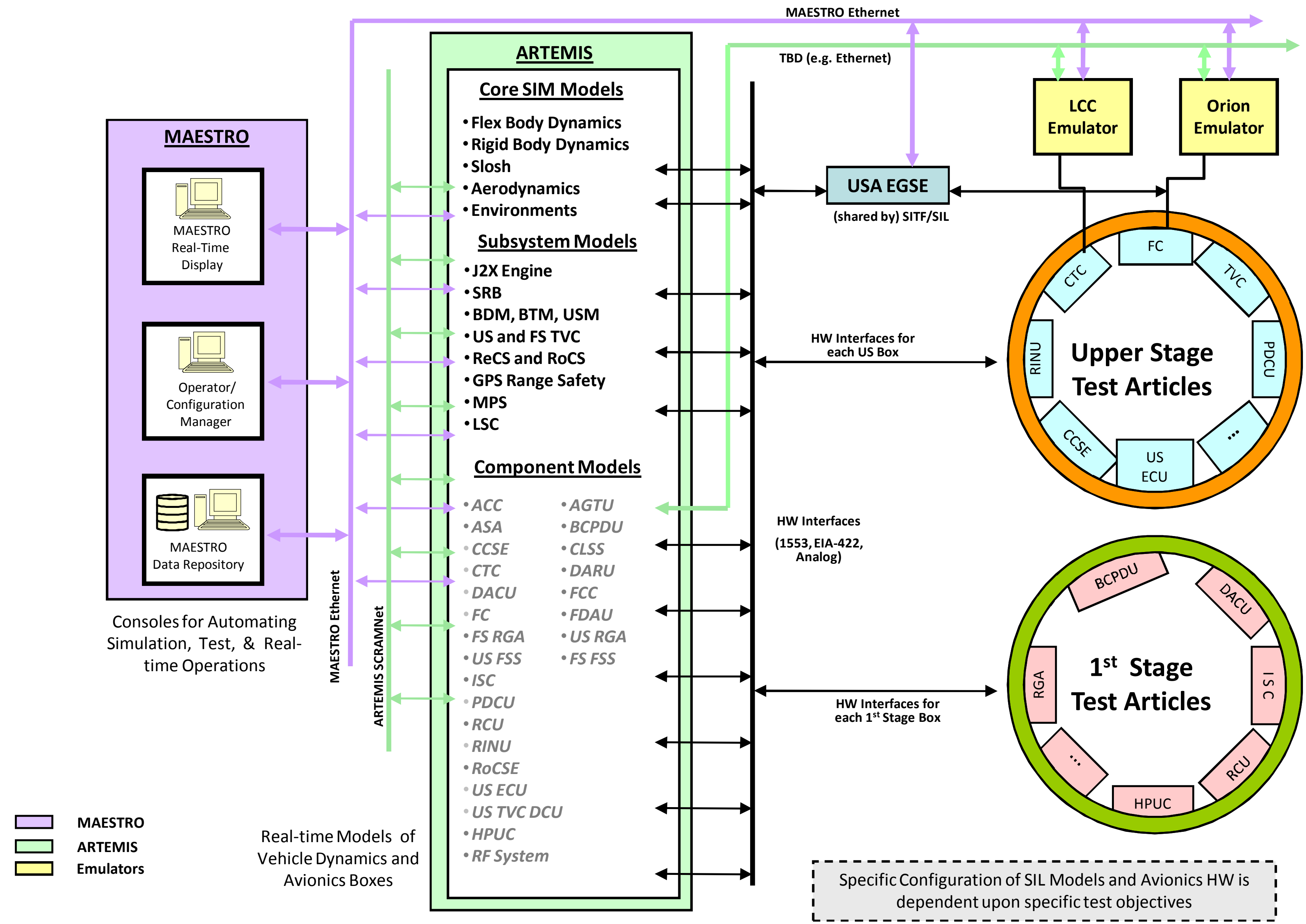
Why ARTEMIS?

- One combined source code tree supporting:
  - Multiple model fidelities
    - Vehicle – flex body, rigid body
    - Selectable winds, atmosphere, TVC nozzle, etc.
  - Non real-time, all-digital
  - Real-time, distributed configurations
    - all-digital, partial HWIL, all HWIL
  - Multiple Ares development and test labs
  - Software portability between Linux distributions
- ARTEMIS operates in a HWIL environment such that a user can select between models of avionics components or interfaces to avionics hardware
- Simulation will interact with lab configuration and control software to support model selection and fault insertion
- Utilizes modern computing technology to achieve real-time performance of high-fidelity models

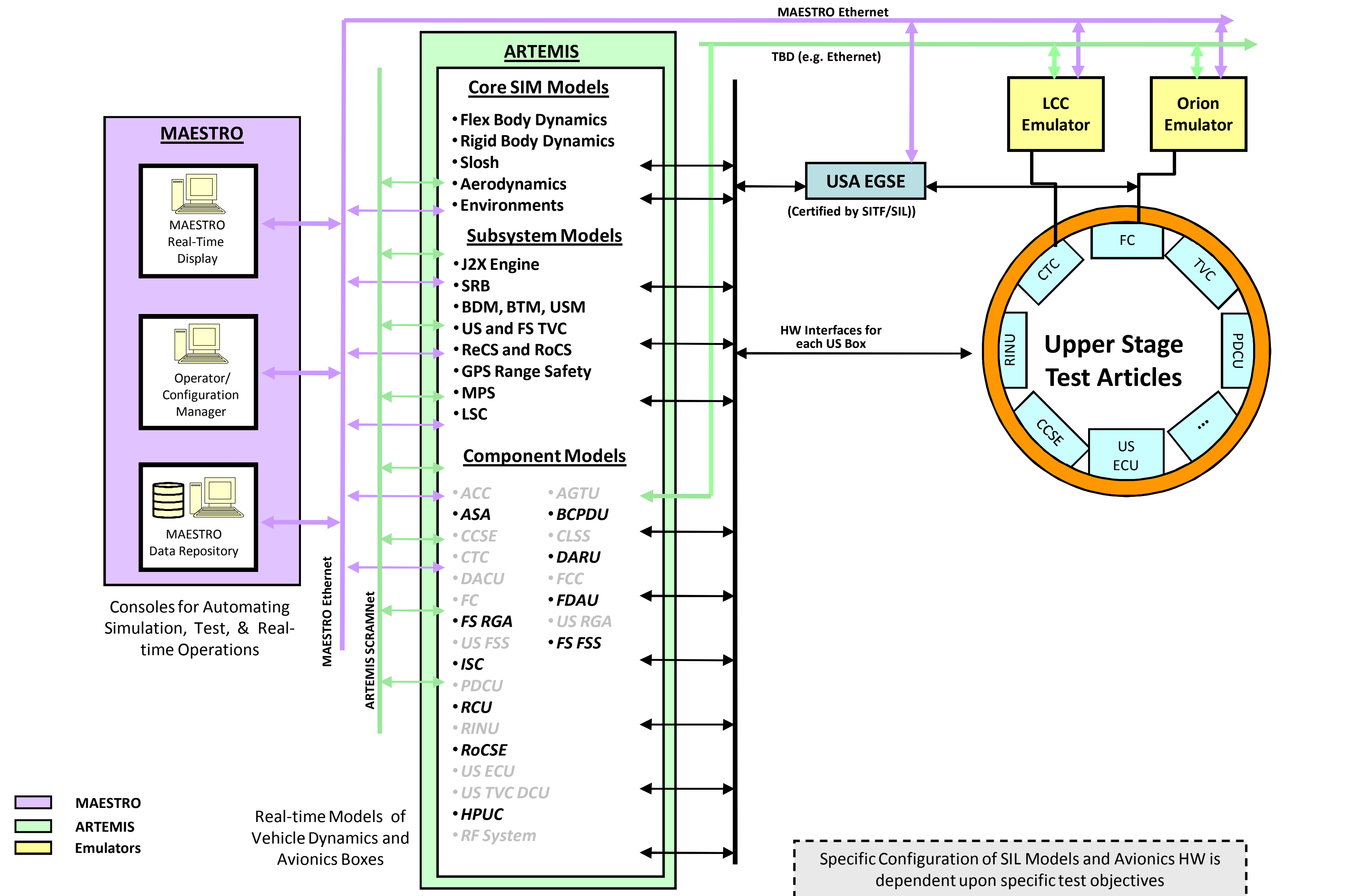
Ares Test Facilities Overview



ARTEMIS SIL Architecture



ARTEMIS SITF Architecture



ARTEMIS Organization

- ARTEMIS is organized into six functional components
  - Simulation
    - Contains the executive framework
  - Timing
    - Scheduling, synchronization, global timing source, time stamps
  - Models
    - Three major categories: Core Simulation, Components, Subsystems
  - Input / Output
    - SCRAMNet, shared memory, discrete, analog, EIA-422, MIL-STD-1553B, Gigabit Ethernet
  - Data Recording
    - Global, local, meta data definition
  - Hardware
    - Computers, I/O cards, cables, racks

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Simulation Overview

- Executive Framework Consisting of:
  - Input data processing of XML input files
  - Multi-phased initialization
  - Scheduled (run-time) loop
    - Derivative / Integration
  - Shutdown
  - Error handling
  - Monte Carlo
  - Fault Insertion

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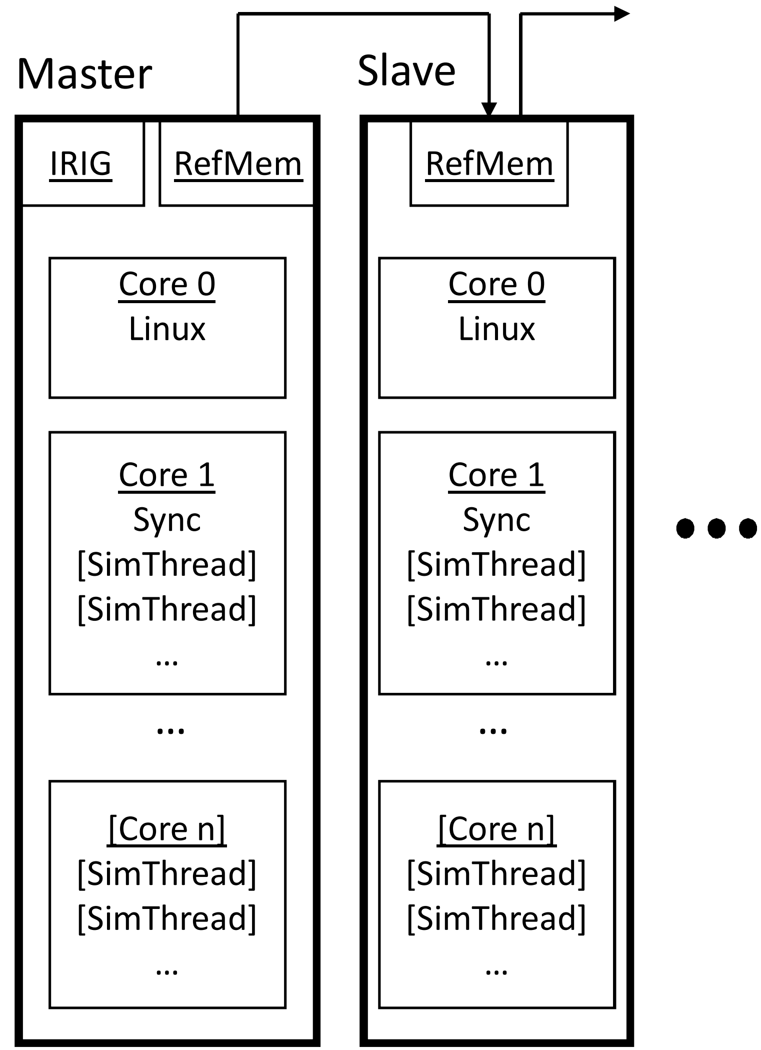
Timing Overview

- Sync controls timing and scheduling of frames for each ARTEMIS executable
  - ARTEMIS executables may run at different frame rates that are a multiple of Sync minor frame rate
- Maintains hard real-time operation using a timing card such as IRIG-B or RCIM
  - Can also run non-real-time
- Creates and controls access to the shared/reflective memory region for ARTEMIS
- Receives and responds to commands from MAESTRO for both Master and Slave Sync
  - MAESTRO passes test configuration and startup commands through Master Sync
  - MAESTRO issues Sync commands to control ARTEMIS execution
  - Sync responds to MAESTRO with status messages

Sync Architecture

- One Master Sync process runs on the Master Node
- Each additional simulation node runs the Slave Sync process that is controlled by Master Sync
- Master node controls real time synchronization via reflective memory
  - Receives timer interrupt from timing card
- Sync Data Coherence
  - Data input at beginning of sim thread's start cycle
  - Data output at end of cycle prior to sim thread's next start cycle



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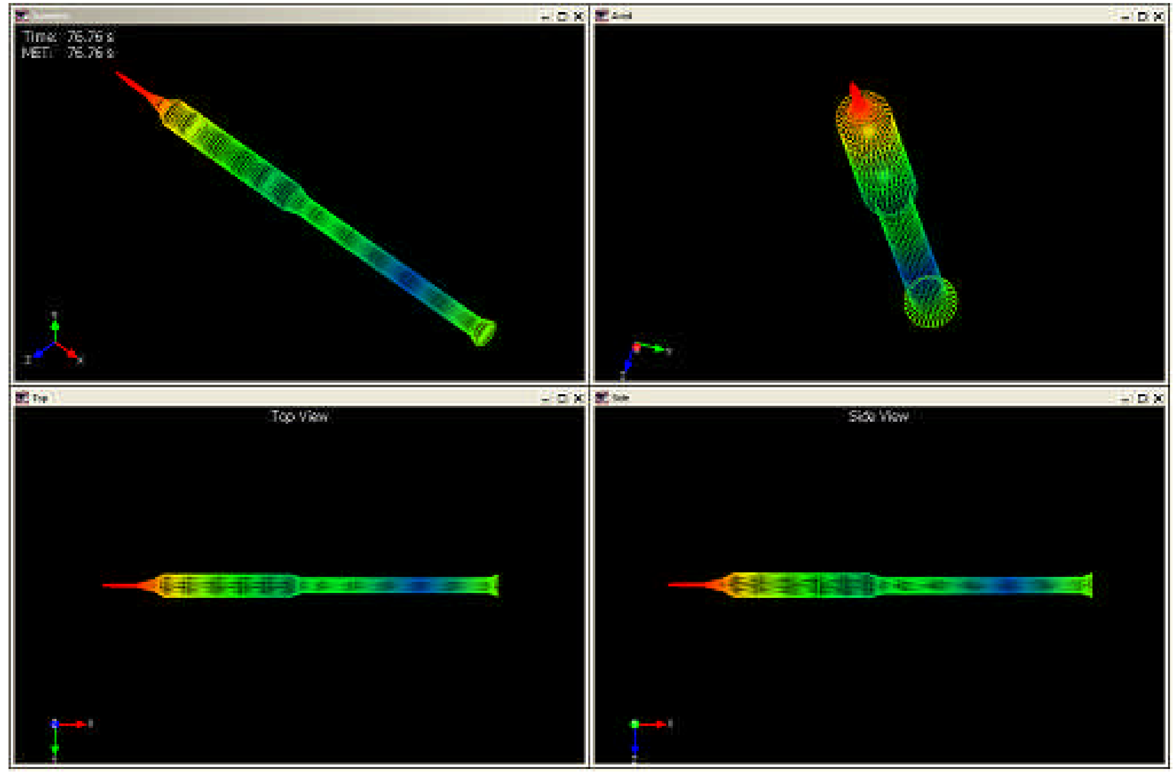
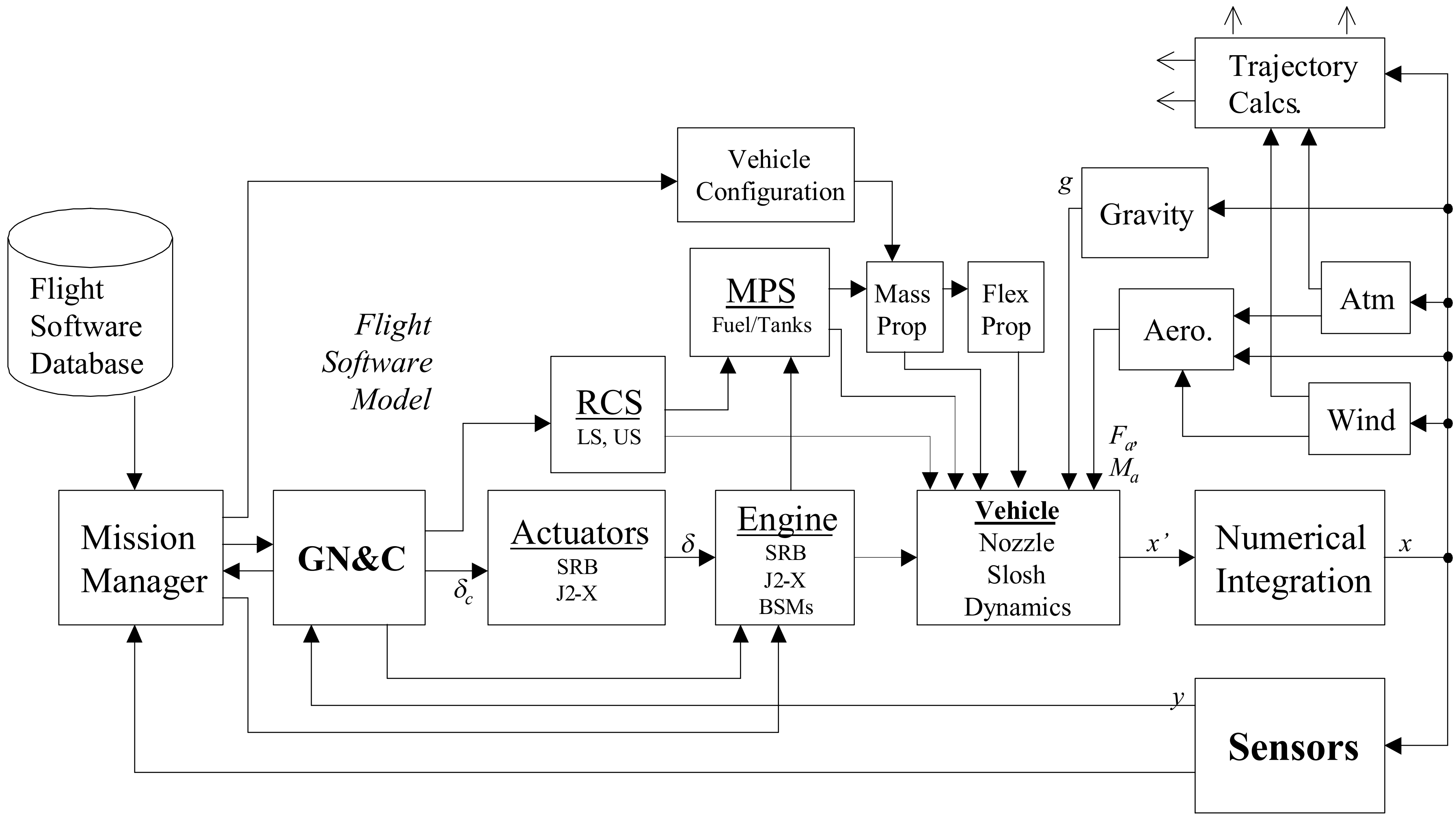
Models Overview

- Core Simulation
  - Flexible and rigid body equations of motion and environment models
- Component
  - Digital models representing the functionality of actual Ares avionics boxes

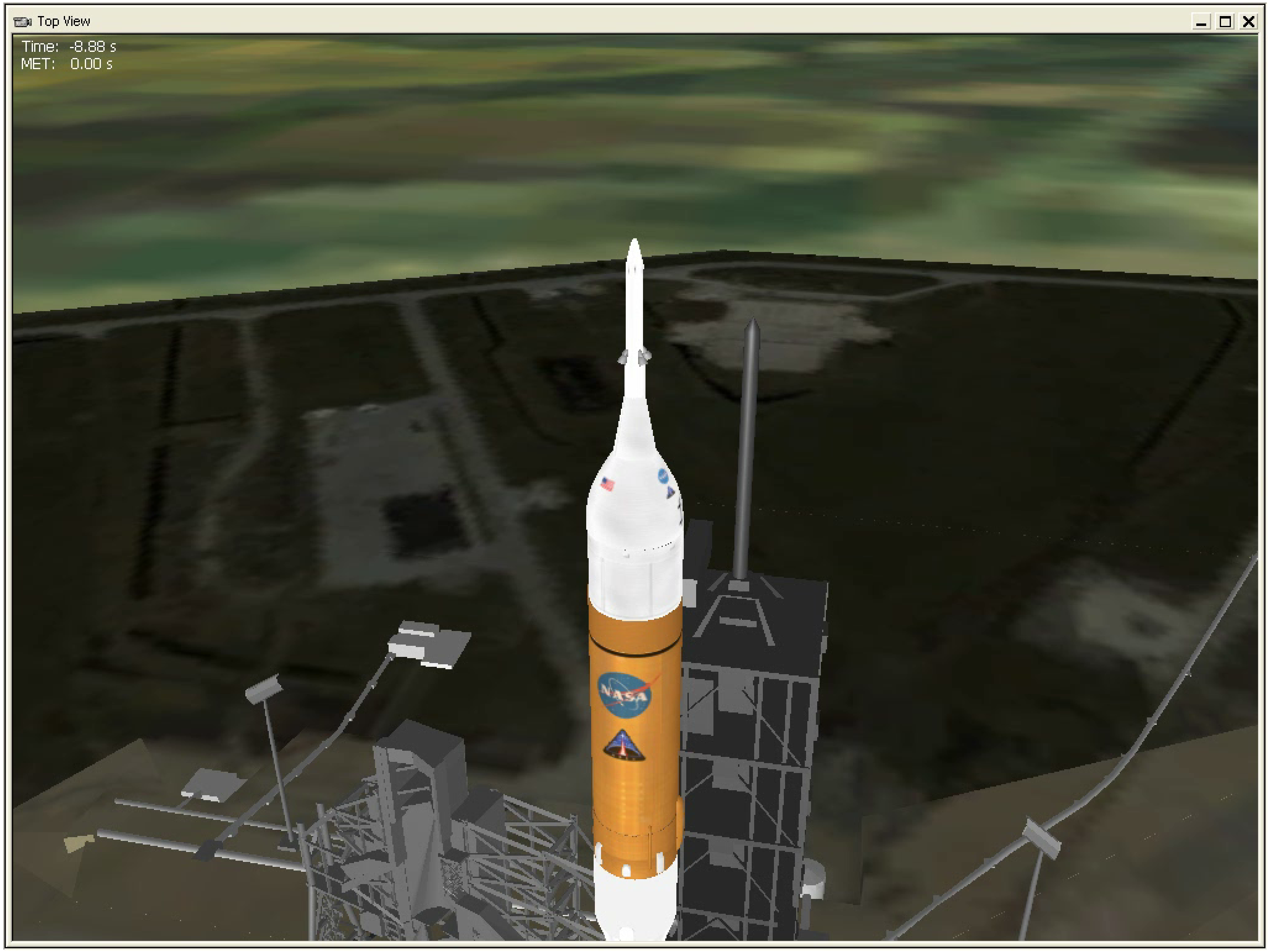


- Subsystem
  - Digital, physics-based models representing the vehicle's physical subsystems that are not typically tested in the lab.

Simulation Block Diagram



ARTEMIS Animation



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I/O Layer Overview

- Provides a transparent, consistent architecture for performing I/O for the ARTEMIS models
- Handles simulated device communication between the models via either shared memory or SCRAMNet reflective memory
- Transfers to real or simulated devices must be transparent to the models
- Handles the following real devices contained in the Ares I avionics architecture:
  - MIL-STD-1553B, EIA-422, Discrete I/O, Analog Sensors, D/A and A/D, Gigabit Ethernet
- Handles other real devices needed by the simulation system such as:
  - GPIB, RCIM II / RCIM III, SCRAMNet GT, IRIG

I/O Layer Overview

- The I/O Layer consists of:
  - A set of common library calls that the ARTEMIS models use for communication with the I/O Layer
  - The I/O Layer process which performs all the I/O with real or simulated devices
  - An XML file describing the configuration of the Ares I avionics rings, simulation computers, and I/O devices used during a simulation
  - A python based GUI that allows a user to build the XML configuration file
  - An I/O Layer library:
    - Contains the initialization, read, write and close calls for each device the models control
    - Communicates with the I/O Layer process via shared memory semaphores
    - Passes unique device information and data from the models to the I/O Layer process via device structures in shared memory
    - The read and write calls communicate directly with the device driver threads

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  - **Data Recording**
    - **Global, local, meta data definition**
  - Hardware
    - Computers, I/O cards, cables, racks

Data Recorder Overview

- Data Recorder supports generic data recording of multiple types of interfaces:
  - SCRAMNet, MIL-STD-1553, Gigabit Ethernet, EIA-422, Discrete I/O, Cross Channel Data Link (CCDL)
- Configured via an XML file
- Data is recorded in its raw format
  - Each packet/message is recorded with a timestamp
- Each interface is recorded in a separate file
  - Filenames contain the beginning and ending timestamp for its corresponding data
- Interfaces with the local MAESTRO daemon
- Provides periodic archiving capability for early analysis during long tests

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  - **Hardware**
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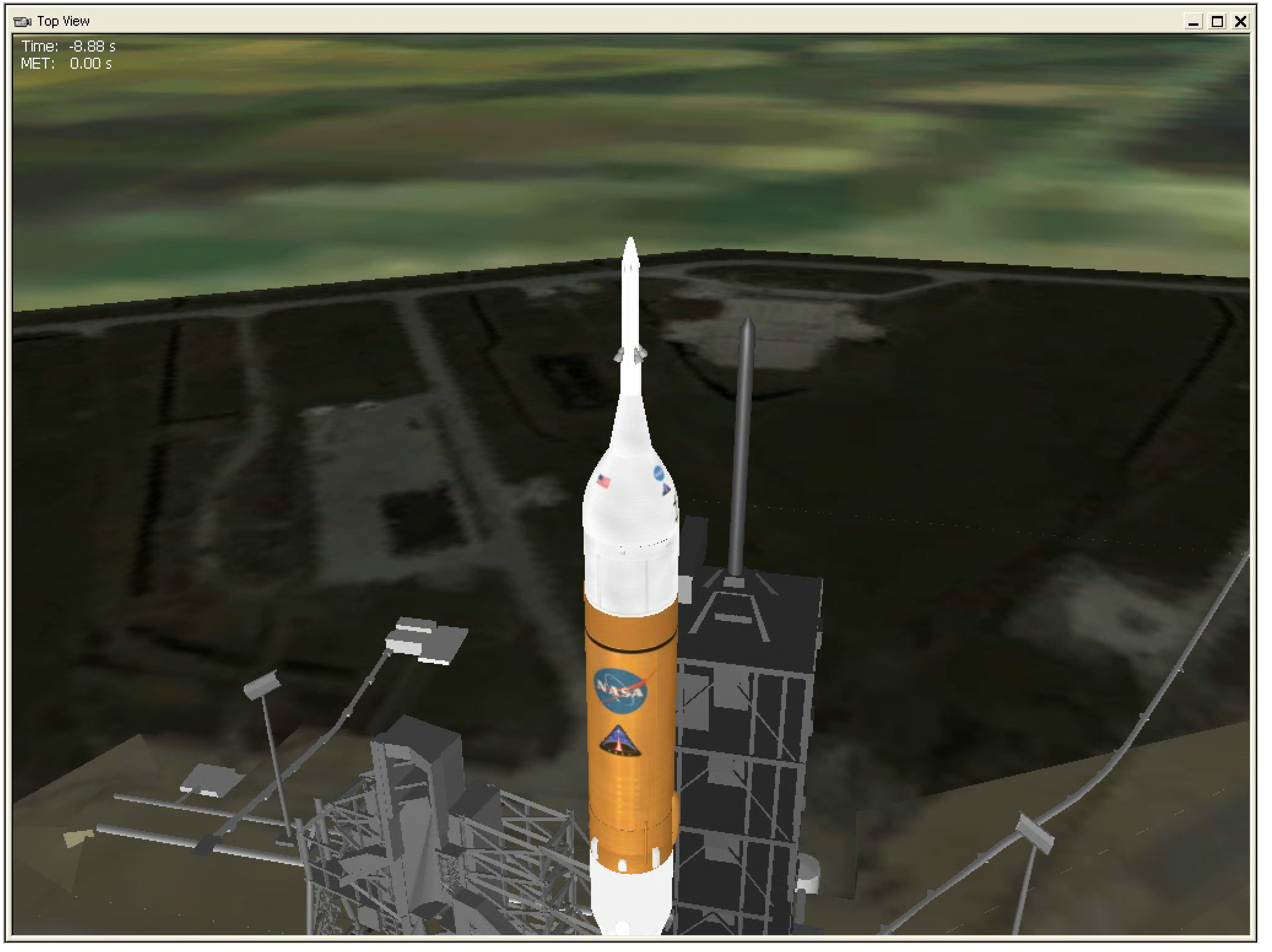
Hardware Overview

- Concurrent RedHawk real-time operating system
  - Devices verified by vendor to meet real-time requirements
- I/O Cards
  - SCRAMNet, MIL-STD-1553, Gigabit Ethernet, EIA-422, Discrete I/O, Analog Sensors, D/A and A/D boards, RCIM, IRIG
- The SIL will have flight-like cables
- All simulated components will be positioned in computer racks near avionics boxes in each ring

Current Status and Future Work

- Current
  - Implementing Ares communications via the I/O Layer
    - 1553B, GbE
  - Integrating preliminary high fidelity vendor models
- Future
  - Support flight software and vehicle testing
  - Integrate all high fidelity vendor models
  - Integrate flight hardware avionics components
  - Transition to Ares V

Questions



Backup Slides

Fault Insertion

- Two Types of Faults
  - Overwrite exposed simulation variables in SCRAMNet
    - Least expensive to implement
    - Limited to exposed simulation variables
    - Won't cover all fault requirements
  - Execute an embedded fault in the simulation
    - Require additional software development and V&V in models to simulate fault
    - Initiated by tripping fault flag in SCRAMNet
    - Need to streamline number of embedded faults
- Fault Insertion Mechanism
  - Peek and Poke via MAESTRO
    - User can trip embedded faults via MAESTRO interface to sync
    - Non-Deterministic
  - Separate fault insertion executable
    - Controlled by sync master
    - Provides logical conditions to determine when fault inserted
    - Input file driven
    - Deterministic

Core Simulation Models

- Stack Dynamics
  - Coupled rigid body and flexible body dynamics formulation which properly accounts for variable mass effects and force following terms
  - Supports all nominal and abort configurations
  - Input data developed from EV30 LA2 structural models
  - Multithreaded partitioned equations to achieve real-time performance with a frame time under 2ms
- Stage Dynamics
  - 6 DOF rigid body formulation with vehicle states defined with respect to Constellation structural frame (fixed point off nose of LAS)
  - Supports all nominal and abort configurations
- Mass Properties
  - Propellant mass computed using mass flow rate defined by engine model
  - Propellant mass properties computed from structural model mass matrices
  - Compute mass properties of each stage from sum of dry structure and propellant
  - Mass properties of stack (or combined stages) computed from sum of stages for current configuration defined by flight phase

Core Simulation Models

- Structural Properties
  - Stage mass and stiffness matrices defined by NASTRAN models
  - Family of propellant mass matrices based on stage mass
  - Assemble stack mass and stiffness matrices from stage and propellant matrices based on vehicle configuration
  - Update generalized vehicle mass and stiffness matrices each time step for coupled flex body EOM
  - All vehicle node geometry extracted from integrated NASTRAN model
- Nozzle Dynamics
  - Rigid body formulation uses discrete nozzle EOM driven by vehicle dynamics, TVC actuator forces, aerodynamic forces, and flex bearing stiffness
  - Rigid body formulation also includes Tail-Wag-Dog effects
  - Flex body formulation utilizes coupled nozzle dynamics embedded in system Ritz vectors or modes
- Slosh Dynamics
  - Rigid body formulation uses discrete slosh masses per tank modeled by spring-mass-damper systems, Lookup tables for slosh parameters
  - Flex body formulation utilizes slosh modes developed from additional effects superimposed on propellant mass and stiffness matrices

Core Simulation Models

- Atmosphere and Winds
  - US76 standard atmosphere model
  - 2007 Global Reference Atmospheric Model (GRAM2007)
  - 1800 Measured Day-of-Launch Winds
  - Ground winds to support pre-launch
- Lumped Aerodynamics
  - Linear 1-D table lookup and Nonlinear 2-D table lookup for aerodynamic coefficients for stack and stages (SRB, LAS, etc)
- Distributed Aerodynamics
  - Aerodynamic data mapped to NASTRAN mesh for loads applied to the stack (primary driver of flex)
- Gravity
  - 3 model options:
    - Kepler
    - J-2, J-3, & J-4
    - Gravity Recovery and Climate Experiment (GRACE)

Component Models

- Flight Computer (FC)
  - Controller algorithm
    - Exact representation of DAC2 Ares Controller algorithms (Gain-scheduled Flex Mitigation Filters + PID)
  - Navigation algorithm
    - Fundamental Navigation Equations for multiple sensors and rate gyros
  - Guidance algorithm
    - Exact representation of DAC2 Ares Guidance algorithms (Open-Loop Profile for 1st Stage; Closed-Loop Algorithm for US)
  - Mission Manager and Event Controller
    - Event handler to control flight and vehicle phasing based on flight time and mission events
- Booster Control & Power Distribution Unit (BCPDU)
  - Passes commands from the flight computer to downstream avionics boxes
  - Prototype MIL-STD-1553 interface from FC with TVC commanded rock and tilt current message
- Sensors
  - Medium-fidelity RINU model with gyroscope and accelerometer error terms (bias, noise, scale factor, misalignments, initial condition errors)

Component Models

- Recovery Control Unit (RCU)
  - Commands the BTM, aeroshell jettison, and forward skirt extension jettison on the first stage during recovery operations
- Ignition & Staging Controller (ISC)
  - Commands the firing of the first stage, BDM, USM, and first stage separation pyros based on commands from the BCPDU
- Altitude Sensor Assembly (ASA)
  - Pressure sensor that activates first stage recovery system once the SRB falls below a given altitude
- Command and Telemetry Computer (CTC)
  - Currently relays ground commands to the FC during pre-launch and ascent
- Rate Gyro Assembly Electronics (RGAE)
  - Buffers the RGA outputs for use in the FC for both the first stage and upper stage RGAs
- Redundant Inertial Navigation Unit Electronics (RINUE)
  - Uses ΔV & $\Delta\theta$ from the RINU to estimate vehicle states & other data needed by the flight software

Component Models

- Combined Control System Electronics (CCSE)
  - Partial CCSE model outputs valve commands to support tanking ground ops. Incorporates previous ReCSE model as well.
- Roll Control System Electronics (RoCSE)
  - Relays the fire commands for the first stage roll control system from the FC to the RoCS thrusters
- Upper Stage Engine Control Unit (US ECU)
  - Controls the J-2X firing, mixture ratio, and throttle
- Upper Stage TVC Data & Control Unit (US TVC DCU)
  - Converts a commanded set of gimbal angles from the FC into a current value used by the upper stage TVC

Subsystem Models

- Reaction Control System (RCS)
  - Ideal thrust, general valve dynamics developed but not activated
  - Lookup tables for thrust & valve dynamics
- Booster Separation Motors (BDM, BTM, Ullage)
  - Uses lookup table for thrust, supports delayed firing
- Engines
  - Lookup table driven, supports separate tables for nominal, startup and shutdown operations
- Thrust Vector Control (US & FS TVC)
  - High-fidelity simplex algorithm with models of servo valves, power spool, and actuator
- Main Propulsion System (MPS)
  - Simple tanking model
  - High fidelity model incorporated using existing ROCETS code

Current Subsystem Models

- Hold-Down Post (HDP)
  - Uses stiffness and damping matrix to model flexibility of launch platform
  - Spring can only provide force while in compression
- Linear Shaped Charges (LSC)
  - Model does not provide forces, but sets flags indication whether stage separation has occurred
- Redundant Inertial Navigation Unit (RINU)
  - Converts sensed vehicle motion signals into ΔV & $\Delta\theta$ values needed by the flight software
- Rate Gyro Assembly (RGA)
  - Senses the vehicle motion and converts to $\Delta\theta$ signals used by the FC controller